

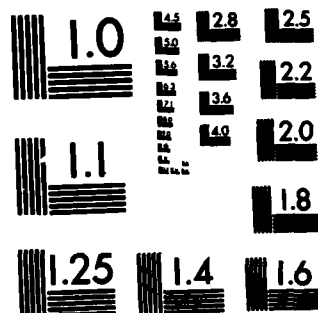
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J P JOHNSTON 30 DEC 82 N00014-79-C-0255

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FINAL REPORT

to

Office of Naval Research  
Project SQUID

on

Contract No. N00014-79-C-0255

entitled

TRANSITORY STALL IN DIFFUSERS

1 March 1979 to 30 September 1982

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## INTRODUCTION

✓ Diffusers have wide application as components of engines for flight vehicles, e.g., airbreathing engine inlets, compressor diffusers, transfer and interstage ducting and combustor inlet diffusers. Their function is to convert the kinetic energy in a high speed stream into static pressure rise with the least possible loss of energy, a process called recovery. Diffusers designed for high pressure recovery are generally close to a state of flow separation, or they already have some intermittent separation occurring in their boundary layers.

Attempts to increase diffusion rates (pressure gradients) beyond certain optima established mainly by diffuser geometry (e.g., ratios of outlet to inlet width or diameter, and so forth) has been shown to push the diffuser into an unsteady flow regime called "transitory stall." Low speed, quasi-periodic oscillations of the boundary layer detachment (separation) region have been observed. The stalled region motions are sometimes observed to be large and accompanied by large fluctuations of pressure.

The study of the transitory stall phenomenon, and the improvement of our empirical base of knowledge for detaching turbulent boundary layers in diffusers were the main objectives of this project. In addition, for purposes of checking some recently developed prediction methods, we attempted to obtain very accurate diffuser pressure recovery data for a two-dimensional diffuser of fixed length to width ratio ( $N/W_1 = 15$ ) and variable opening angle ( $2\theta = 0$  to 24 degrees) which operated in the unstalled and the transitory stall flow regimes.

## SUMMARY OF ACCOMPLISHMENTS

1. A closed circuit wind tunnel for experiments on diffusers with inlet air speeds up to 150 ft/sec and Reynolds numbers based on inlet width of  $U_1 W_1 / \nu = 2.2 \times 10^5$  was constructed and qualified. This tunnel was designed to provide very low turbulence and low internal acoustic pressure fluctuations at the diffuser test section.
2. Diffuser performance data were obtained. These data included detailed wall pressure distributions, and distributions of forward flow fraction along the diffuser walls. The results are presented at a large number of opening angles in the range  $2\theta = 4$  to 24 degrees for one turbulent inlet boundary layer of blockage ratio,  $b_1 = 0.03$ . The data have very low experimental uncertainties for this class of experiment.
3. Detailed data on boundary layer behavior along the diffuser walls up to the detachment point were obtained for one diffuser in the transitory stall regime, at  $2\theta = 10$  degrees.
4. Wall pressure fluctuation data were obtained for wall angle settings from  $2\theta = 6$  to 24 degrees. These results showed that although fluctuations do exist in the transitory stall regime, they are not very large in our apparatus compared to other reported results, e.g., Smith and Kline.

5. Based on pressure fluctuation results and the forward flow fraction data of this study and by comparison to the work of others, we concluded that the large scale, very low frequency fluctuations associated in the past with the transitory stall regime are not inherent in the diffuser flow itself. In all likelihood the fluctuations are system specific and result from a response to, and amplification of external, low frequency flow fluctuations. In the transitory stall regime, the location of the detachment region is very sensitive to slow disturbances. These disturbances were small in our experiments and consequently the resulting fluctuations of pressure were smaller than previously encountered.
6. In addition to the base data noted above, the effects of opening angle assymetry were studied, and some preliminary work carried out concerning the superposition of high levels of turbulence in the entering boundary layers.
7. Some progress was made on the development of prediction methods for two-dimensional diffusers with end wall effects included.
8. New general knowledge on the behavior of turbulent boundary layers at detachmebnt (separation) has been gained and applied to the development of improved models of flow behavior in the detachment region.

#### DISCUSSION

A very important aspect of this program has been the development and application of two new flow measuring devices, the thermal tuft and the pulsed wall probe. These two instruments were developed for parallel studies of turbulent flow reattachment but substantial contributions to their development were also made by this program.

In particular, the thermal tuft, the instrument which measures the instantaneous direction (forward or reverse) of the wall layer fluid, was used here to obtain the distributions of forward flow friction in the wall layers. These data provided invaluable diagnostic information which permit clear interpretation of the static pressure recovery profiles along the diffuser. It is shown, for example, that pressure recovery continues, downstream of turbulent detachment for diffusers in the transitory stall regime.

The pulsed wall probe provides data on the mean value and fluctuations of the wall skin friction upstream, in and downstream of turublent detachment. This probe was used in our study of the details of a detaching flow of the diffuser of  $2\theta = 10$  degrees. It shows that the mean skin friction values in the region of reverse flow ( $\alpha < 0.5$ ) downstream of detachment are 4 to 5 times larger than current diffuser predictions allow. Because of its recent development this instrument was only employed late in our program, but will be employed extensively in future work.

In conclusion, our work to date on the development of these new instruments, the thermal tuft in particular, is having an impact on studies of separating and reattaching flows in other laboratories. For example, Simpson

at SMJ has contributed to the development of the tuft and has used it in his recent work under ONR contract. We have knowledge of others who are also starting to employ this technique.

#### FUTURE PLANS

Having established that large scale, low frequency motions of the detachment region are not an inherent feature of the transitory stall regime, and having shown that our wind tunnel behaves well in this region, we have started to examine the important question of the behavior of complex entry flows in adverse pressure gradients.

A feature never before examined in detail, but one which deserves careful consideration concerns turbulent boundary layers at diffuser entry which have much higher than normal rates of entrainment and shear stress in their outer layers. It is well known that longitudinal mixing created by vortex generators delays stall and improves pressure recovery performance. In addition, we have shown that the highly turbulent boundary layer downstream of a turbulent reattachment point also detaches less readily than an equivalent equilibrium layer subject to the same separating pressure gradient.

Our future efforts will concentrate on providing the detailed experimental documentation of several cases of detaching turbulent flow subject to increased outer layer mixing created upstream by separation and subsequent reattachment before the flow enters the adverse pressure gradient. In addition, we hope to use this new data to improve existing engineering calculation methods for this type of disturbed inlet flow which incidentally is not uncommon in practical applications.

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